Sound Waves

Doppler Effect

Doppler effect causes the received frequency of a source to differ from the sent frequency if there is motion that is increasing or decreasing the distance between the source and the receiver. This effect is readily observable as variation in the pitch of sound between a moving source and a stationary observer.

Doppler Effect

- The *Doppler effect* for sound is the shift in frequency when there is motion of the source of sound, or the observer, or both.
- The Doppler shift results from the relative velocity of the sound source and the observer. As the observer approaches the stationary source, the relative velocity is larger, resulting in an increase in the wave crests reaching the detector each second
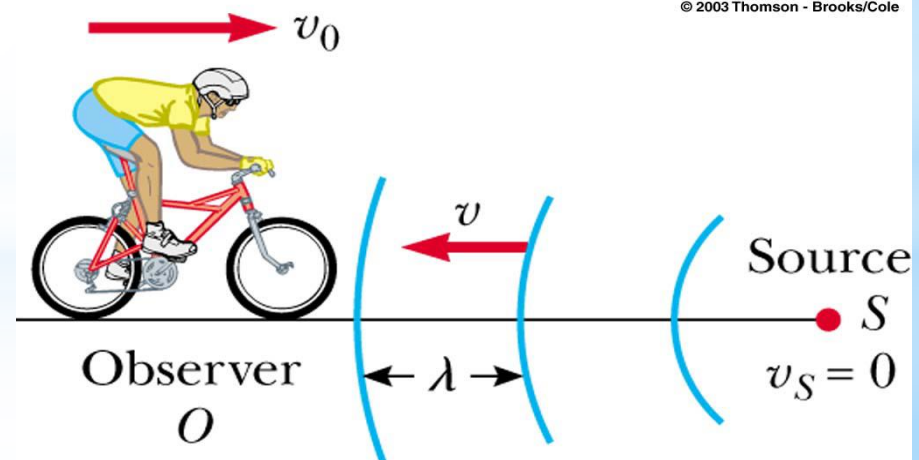
When not moving,

$$f = v/\lambda$$
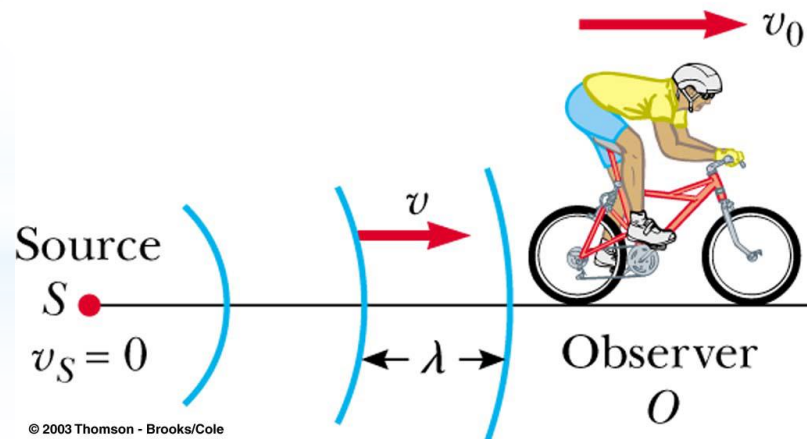
When moving,

$$f' = (v + v_{obs})/\lambda$$

$$f' = f\left(\frac{v + v_o}{v}\right)$$

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v_0

v

Source
S
$v_S = 0$

$\leftarrow \lambda \rightarrow$

Observer
O

If observer moves away:

As the observer recedes from the source, the relative velocity is smaller, resulting in a decrease in the wave crests reaching the detector each second.

$$f' = f\left(\frac{v - v_o}{v}\right)$$

Source
S
$v_S = 0$

v

$\leftarrow \lambda \rightarrow$

v_0

Observer
O

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Doppler Effect
Source in Motion

As the source moves toward the sound detector, Observer A in **Figure** , more waves are crowded into the space between them. The wavelength is shortened to λ'. Because the speed of sound is not changed, more crests reach the ear per second, which means that the frequency of the detected sound increases.

$$\lambda' = \lambda - v_s T$$

$$= \lambda - v_s \frac{\lambda}{v}$$

$$= \lambda(1 - v_s/v)$$

$$f' = v/\lambda'$$
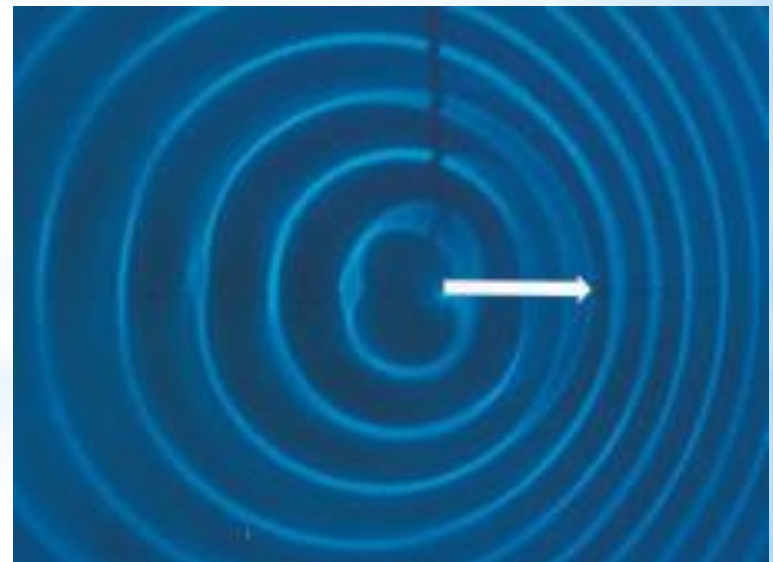
$$f' = f \frac{v}{v - v_s}$$

Doppler Effect, Source in Motion

The observed frequency is increased whenever the source is moving toward the observer.

Approaching source:

$$f' = f \frac{v}{v - v_s}$$

When the source moves away from a stationary observer. The observer measure a greater wavelength and hears a decreased frequency.

Source leaving:

$$f' = f \frac{v}{v + v_s}$$

Beats

When two sound waves whose frequencies are close, but not the same, are superimposed, a striking variation in the intensity of the resultant sound wave is heard. This is the **beat** phenomenon. The wavering of intensity occurs at a frequency which is the difference between the two combining frequencies.

$$s_1 = s_m \cos \omega_1 t \qquad \text{and} \qquad s_2 = s_m \cos \omega_2 t,$$

$$s = s_1 + s_2 = s_m(\cos \omega_1 t + \cos \omega_2 t).$$

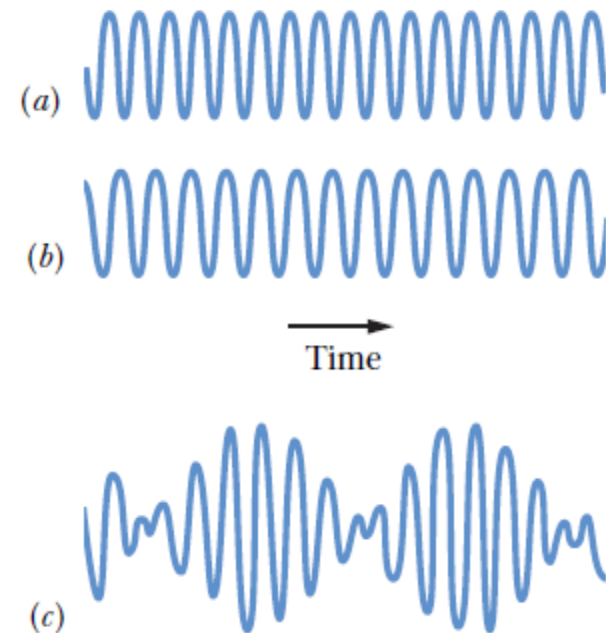$$= 2s_m \cos[\tfrac{1}{2}(\omega_1 - \omega_2)t] \cos[\tfrac{1}{2}(\omega_1 + \omega_2)t].$$

$$\omega' = \tfrac{1}{2}(\omega_1 - \omega_2) \qquad \text{and} \qquad \omega = \tfrac{1}{2}(\omega_1 + \omega_2)$$

$$s(t) = [2s_m \cos \omega' t] \cos \omega t.$$

$$\omega \gg \omega'$$

$$\omega_{beat} = 2\omega' = (2)(\tfrac{1}{2})(\omega_1 - \omega_2) = \omega_1 - \omega_2.$$

$$f_{beat} = f_1 - f_2 \qquad \text{(beat frequency).}$$

Fig. 17-17 (a, b) The pressure variations Δp of two sound waves as they would be detected separately. The frequencies of the waves are nearly equal. (c) The resultant pressure variation if the two waves are detected simultaneously.

Standing Sound Waves

- Sounds of different frequencies are made by standing waves.
- A particular sound is selected by designing the length of a vibrating system to be resonant at the desired frequency.

- If a tube has one open and one closed end, the open end is a region of maximum vibration of air molecules—an antinode. The closed end is where no vibration occurs—a node.
- At the closed end, only a small amount of the sound energy will be transmitted; most will be reflected. At the open end, of course, much more sound energy is transmitted, but a little is reflected. Only certain wavelengths of sound will resonate in this tube, which depends on it length.

Wavelength Formula: 1 Open End
(tube of length L)

This time the pattern is different:

$$L = \frac{n\lambda}{4}$$

or,
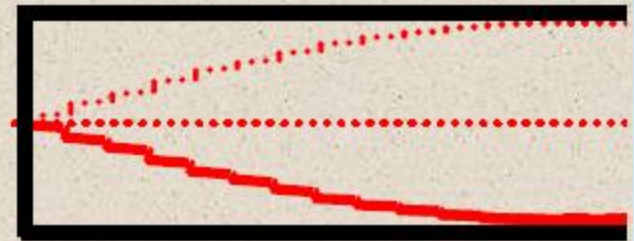
$$\lambda = \frac{4L}{n}$$

where $n = 1, 3, 5, 7, \ldots$

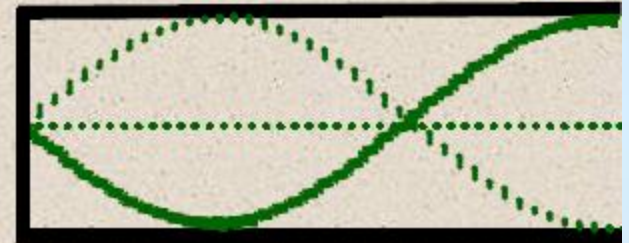Note: only odd harmonics exist when only one end is open.
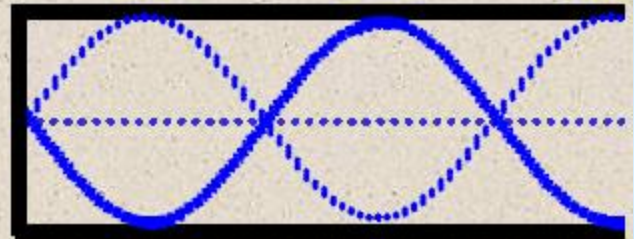
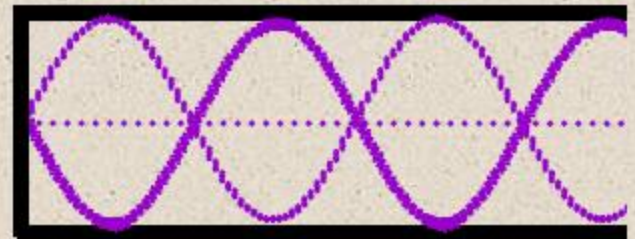$$L = \frac{1}{4}\lambda$$
$n = 1$

$$L = \frac{3}{4}\lambda$$
$n = 3$

$$L = \frac{5}{4}\lambda$$
$n = 5$

$$L = \frac{7}{4}\lambda$$
$n = 7$

The general result for standing waves in a tube open at one end and closed at the other is

$$\lambda_n = \frac{4L}{n}$$ where n=1, 3, 5,.... n (odd values only!!)

$$f_n = \frac{v}{\lambda_n} = \frac{nv}{4L} = nf_1$$ f_1 is the fundamental frequency.

Wavelength Formula:
2 Open Ends
(tube of length L)

As with the string, the pattern is:
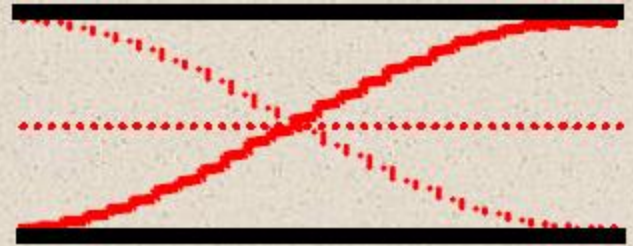
$$\lambda = \frac{2L}{n}$$

where n = 1, 2, 3, ….

Thus, only certain wavelengths will reinforce each other (resonate). To obtain tones corresponding to other wavelengths, one must change the tube's length.
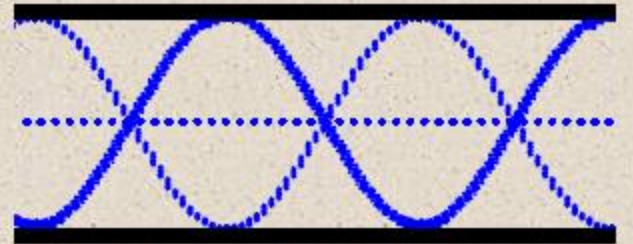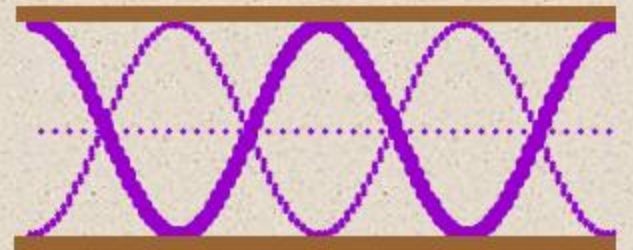
$\lambda = 2L$

$n = 1$

$\lambda = L$

$n = 2$

$\lambda = \frac{2}{3}L$

$n = 3$

$\lambda = \frac{1}{2}L$
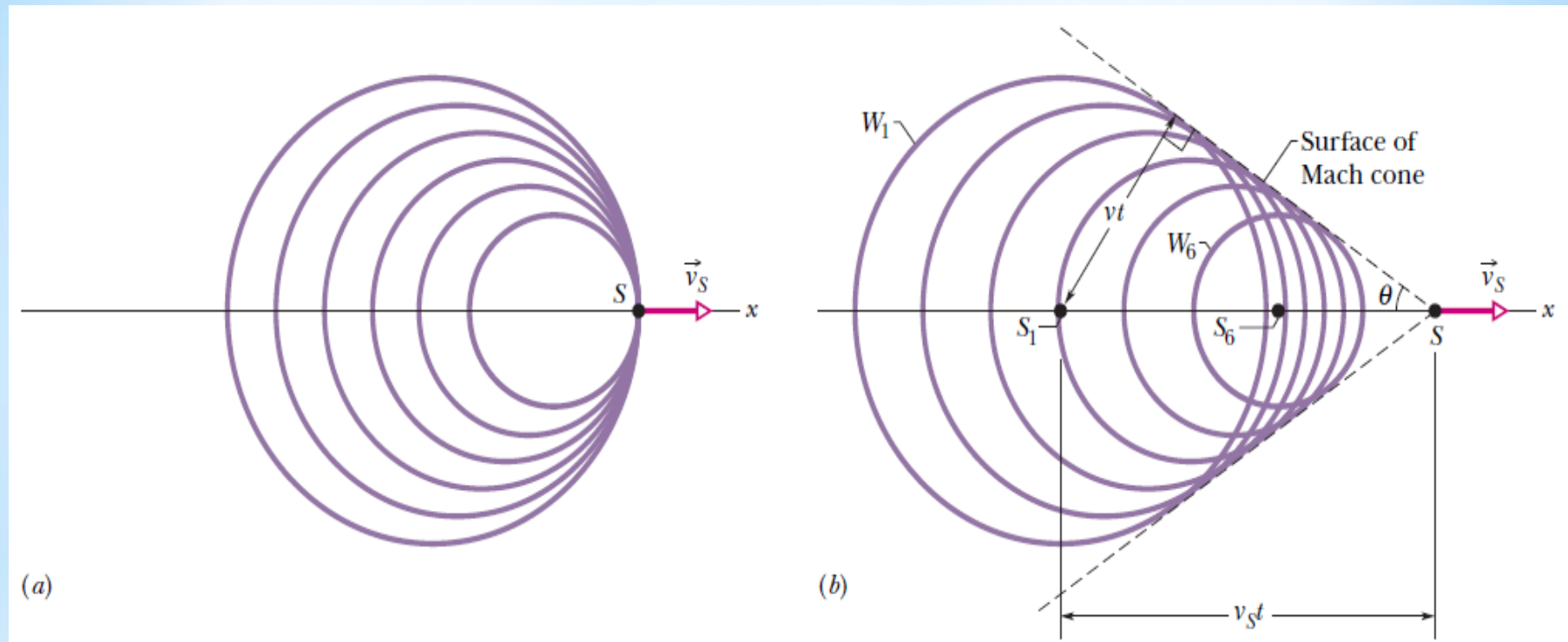
$n = 4$

Shock Waves (Sonic Booms)

❑**Shock Waves** : a sharp change of pressure in a narrow region traveling through a medium, especially air, caused by a body moving faster than sound speed.

❑   **When the source velocity approaches the speed of sound**

Supersonic Speeds, Shock Waves

Fig. 17-22 (*a*) A source of sound *S* moves at speed v_S equal to the speed of sound and thus as fast as the wavefronts it generates. (*b*) A source *S* moves at speed v_S faster than the speed of sound and thus faster than the wavefronts. When the source was at position S_1 it generated wavefront W_1, and at position S_6 it generated W_6. All the spherical wavefronts expand at the speed of sound *v* and bunch along the surface of a cone called the Mach cone, forming a shock wave. The surface of the cone has half-angle θ and is tangent to all the wavefronts.

$$\sin \theta = \frac{vt}{v_S t} = \frac{v}{v_S} \qquad \text{(Mach cone angle)}.$$

The ratio v_S/v is called the *Mach number.*

➤ **Mach number**: the ratio of the speed of a body to the speed of sound in the surrounding medium.

➤ Jet airplanes traveling at supersonic speeds produce shock waves, which are responsible for the loud " sonic boom" one hears. The shock wave carries a great energy concentrated on the surface of the cone with great pressure variations.